PVD Silicon Carbide as a Thin Film Packaging Technology for Antennas on LCP Substrates for Harsh Environments

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***Abstract* — This paper describes an effort to develop a thin film packaging technology for microfabricated planar antennas on polymeric substrates based on silicon carbide (SiC) films deposited by physical vapor deposition (PVD). The antennas are coplanar waveguide fed dual frequency folded slot antennas fabricated on liquid crystal polymer (LCP) substrates. The PVD SiC thin films were deposited directly onto the antennas by RF sputtering at room temperature at a chamber pressure of 30 mTorr and a power level of 300 W. The SiC film thickness is 450 nm. The return loss and radiation patterns were measured before and after the SiC-coated antennas were submerged into perchloric acid for 1 hour. No degradation in RF performance or physical integrity of the antenna was observed.**

***Index Terms* — folded slot antenna, liquid crystal polymer, physical vapor deposition, silicon carbide.**

I. Introduction

Wireless communications systems based on microfabricated antennas have become a leading approach to address some of the key technical challenges facing implementation of wireless sensors in harsh environment applications. A packaging technology for these microsystems must protect the antenna while not compromising its RF performance or negating the benefits of minaturization. As such, the use of mechanically and chemically robust thin films that are transparent to electromagnetic radiation as the package itself is an attractive option. The ability to integrate the fabrication of the package and the device into one process offers a great advantage from both the design and cost perspectives. Most conventional packaging approaches require extra manufacturing steps to complete the packaging process and are not based on robust thin films [1–3].

In a previous study [4], we showed that silicon carbide (SiC) films deposited by plasma enhanced chemical vapor deposition (PECVD) could be used as a thin film packaging material for microfabricated antennas. These films, deposited on dual frequency, folded slot antennas that used Au metallization on alumina substrates, provided excellent protection against reagents known to aggressively attack Au. Moreover, the return loss and gain of the SiC coated antennas were essentially indistinguishable from the uncoated antennas.

Although PECVD SiC showed promise as a thin film packaging material, the relatively high deposition temperature (~ 300ºC) limits its use to substrates that can tolerate such processing temperatures. Unfortunately, for antennas fabricated on most polymeric substrates that are lower cost and conformal to the environment being monitored by the sensor, much lower deposition temperatures are required. One such polymer is liquid crystal polymer (LCP), which has been shown to be an excellent substrate material for microfabricated antennas [5, 6]. However, the maximum processing temperature for LCP is roughly 300ºC. Therefore, the PECVD process described in [4] is not a feasible deposition method. Fortunately, SiC thin films can be deposited at room temperature by physical vapor deposition (PVD) from a SiC target in a conventional magnetron sputtering system. The purpose of this study is to assess whether sputter deposited SiC could be used as a thin film packaging technology for microfabricated antennas on temperature sensitive polymeric substrates.

The antenna used in this paper is a dual frequency folded slot antenna, shown in Fig. 1, and is the same as used in [4] but with several changes needed to adjust to the PVD sputtered SiC film. The antenna resonates at 5.6 and 7.7 GHz and utilizes a self-matched impedance technique to better match the antenna input impedance to the characteristic impedance (Z_0) of the feed line. The return loss and radiation patterns of the SiC-coated antenna are measured before and after the antenna is submerged in perchloric acid, which is a Cr etch that should attack the upper metal layer of the antenna. Note that the choice of the antenna is not important for the purpose of demonstrating the novel SiC packaging technology and was chosen because it is similar to the antenna in [4].

II. Antenna Design and Fabrication

A dual frequency folded slot antenna was fabricated on LCP, which has a dielectric constant and thickness of 2.94 and 50 µm, respectively [7]. The antenna and coplanar waveguide (CPW) feed line consist of a Au thin film (1 µm) layer sandwiched between two Cr layers (50 nm and 20 nm, respectively) to promote adhesion to the LCP and to the SiC film. The metal layers were deposited by an E-beam evaporator and defined by an etch-back process.

The SiC film was deposited at room temperature by PVD from a SiC target in a conventional RF magnetron sputtering system at a chamber pressure of 30 mTorr and a power level of 300 W. The SiC film thickness is 450 nm. A small area on the CPW feed was masked off during the SiC deposition so that an SMA connecter could be soldered to the chrome metal layer to simplify the characterization of the return loss and radiation patterns. The dimensions of the CPW feed line are S = 1.7 mm and W = 0.3 mm, which results in a Z_0 of approximately 70 Ω. The antenna was designed to operate at 5 GHz and 7 GHz with $\lambda_0/2$ mean path lengths of 34 and 21 mm, respectively.

To demonstrate the use of the PVD deposited SiC as a protective barrier for harsh environment sensors and wireless communication circuits, the antenna was dipped into a bath of perchloric acid at 25°C for 60 min. Perchloric acid is an aggressive Cr etchant that rapidly attacks exposed Cr surfaces. During the acid soak, the exposed metal and soldered SMA adapter were held out of the bath so they would not be damaged.

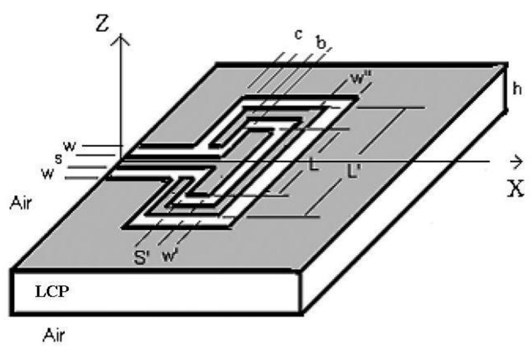


Figure 1: Dual frequency folded slot antenna.

III. Experimental Results

The return loss of the folded slot antenna was measured on an Agilent E8361C Precision Network Analyzer (PNA) before and after the antenna was submerged in perchloric acid for 1 hour. A coaxial short-open-load calibration was performed, which places the reference plane at the SMA connector.

Figure 2 shows the measured return loss of the folded slot antenna before and after the perchloric acid etch. The antenna exhibits a return loss better than 10 dB at both 5.6 and 7.7 GHz. It is seen that the Q of the resonances, the frequency of the resonances, and the magnitude of the return loss is not affected by the perchloric acid bath, which is an indication that the SiC film and the antenna metallization are not affected by the acid bath.

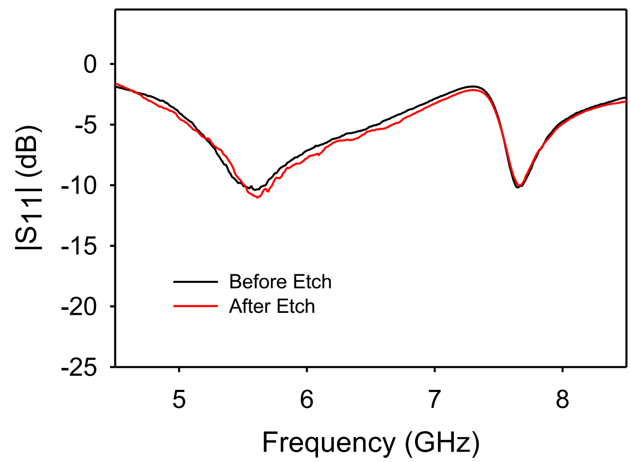
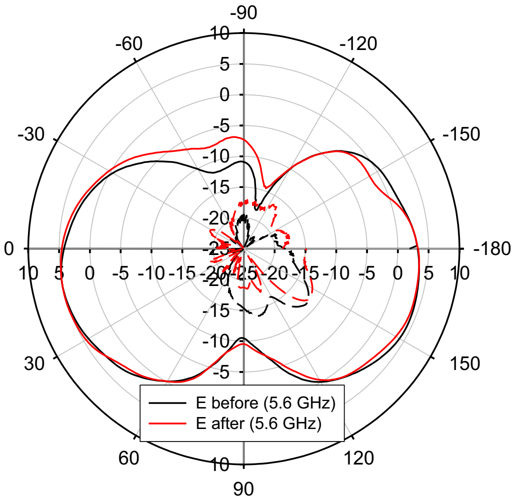


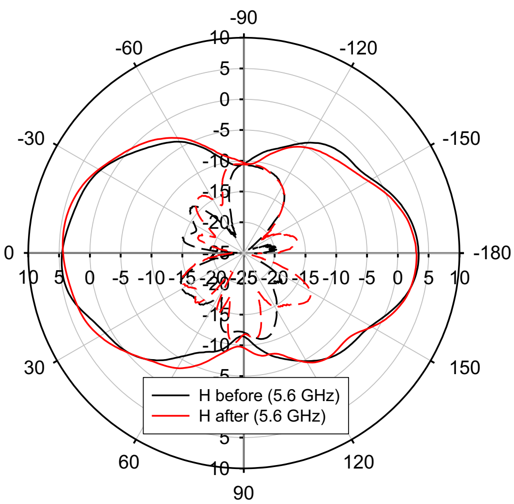
Figure 2: Measured return loss of the folded slot antenna before and after perchloric acid etch.

The radiation patterns were measured in an anechoic chamber. For characterization, the thin LCP was placed between two pieces of Styrofoam. It was noticed that the antenna could be conformed to the Styrofoam without any damage to the SiC, but further tests are required to determine the minimum bending radius of the SiC coated antenna before damage. A 500 MHz to 10 GHz wideband gain horn was used as the transmit antenna and the gain was calculated using the substitution method.

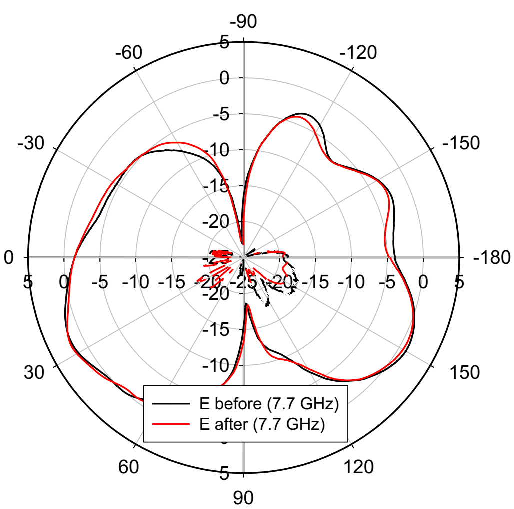
The radiation patterns (E- and H-co and cross pol) at 5.6 and 7.7 GHz before and after etch are shown in Figs. 3a-3d. There is a skewing of the radiation patterns caused by the SMA connector and the cable; this is especially apparent in the E-plane plots when the connector and cable blocked the antenna. The radiation patterns before and after etch are nearly identical, and the measured gain of the antenna, obtained from the H-plane plots because of the mentioned blockage during the E-plane measurements, before and after etch is 4.62 and 4.47 dBi at 5.6 GHz and -1.54 and -1.40 dBi at 7.7 GHz, which is well within the measurement errors due to the placement of the antenna in the Styrofoam block. This further demonstrates that the acid bath did not affect the SiC coated thin film antenna on LCP.



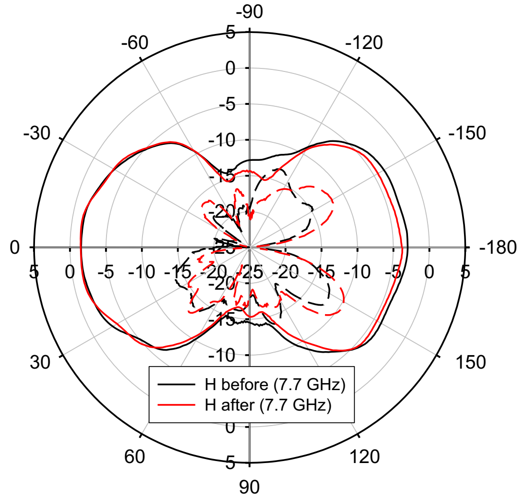
(a)



(b)



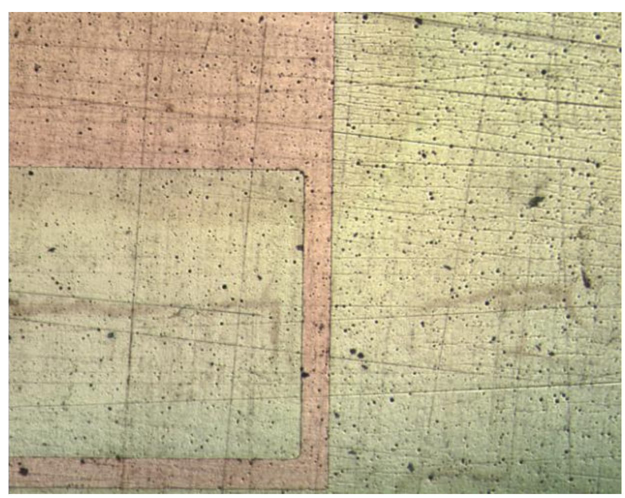
(c)



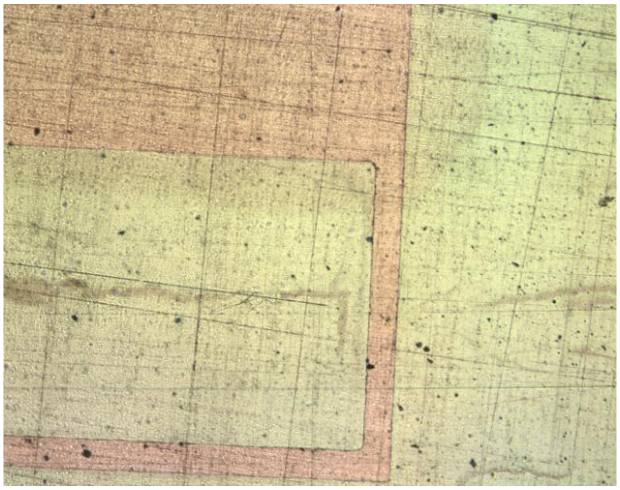
(d)

Figure 3: Measured (a) Eco- and E-cross at 5.6 GHz, (b) Hco- and H-cross at 5.6 GHz, (c) Eco- and E-cross at 7.7 GHz and (d) Hco- and H-cross at 7.7 GHz radiation patterns before and after perchloric acid etch.

Figures 4a and 4b shows a microphotograph of the top view of a section of the radiating slots of the folded slot antenna before and after etch, respectively. It appears that defects on top of the SiC are removed during the perchloric acid etch. To confirm this, SEM photographs were taken and are shown in Figs. 5a and 5b. Hereto, it is observed that the surface of the SiC on metal and LCP is smoother after the perchloric acid etch. Without further experiments, it is unclear if the SiC has been etched by the perchloric acid or if particulates and defects on the SiC were removed during the etch.

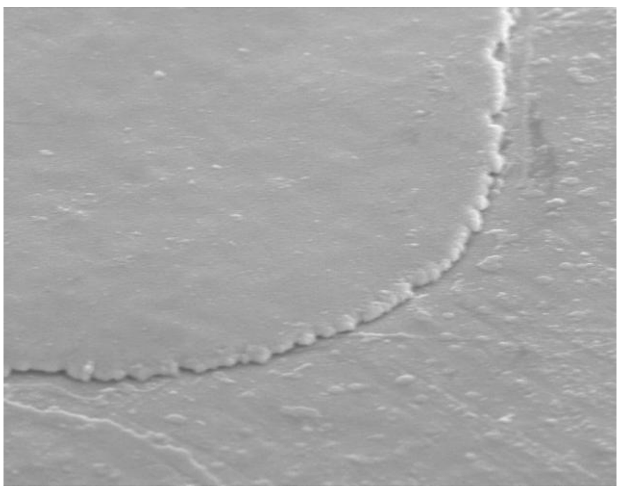


(a)

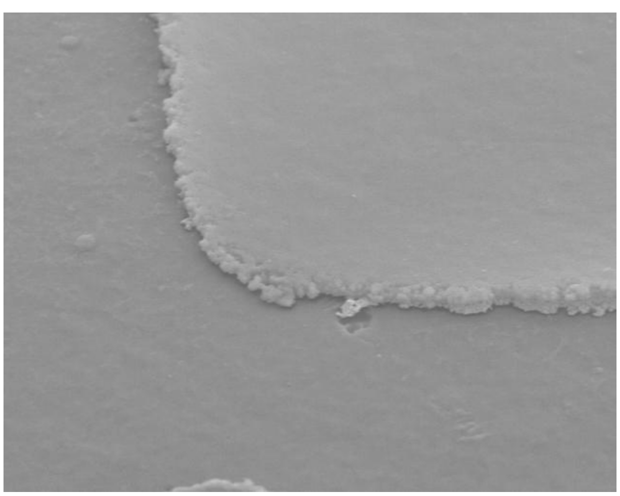


(b)

Figure 4: Microphotograph of a part of the antenna (a) before etch and (b) after etch.



(a)



(b)

Figure 5: SEM of a part of the antenna (a) before etch and (b) after etch.

IV. Conclusion

A folded slot antenna has been fabricated on LCP and coated with a PVD SiC thin film as a protectant for harsh environments. The antenna was characterized before and after an hour long submersion in a perchloric acid etchant. The RF performance after the acid etched showed no discernable differences from before etching. Additionally, the physical structure of the antenna remained intact with no changes. Thus, PVD SiC is shown to provide a feasible chemical packaging technique for harsh environments.

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